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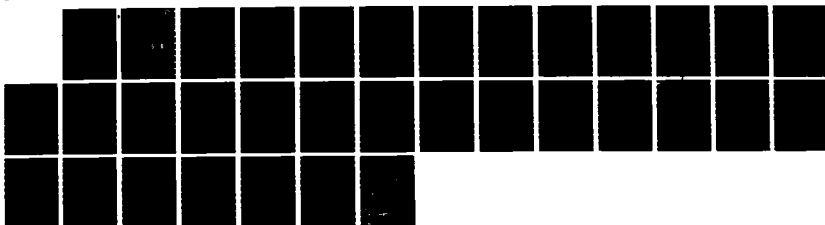
KELVIN: AN INTERACTIVE COMPUTER CODE FOR THE KELVIN
SPECTRUM WITH VISCOUS CORRECTIONS(U) NAVAL RESEARCH LAB
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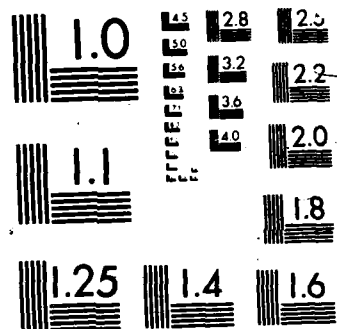
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Kelvin: An Interactive Computer Code for the Kelvin Spectrum with Viscous Corrections

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<p>✓ A detailed description is given of computer code KELVIN, which calculates the amplitude spectrum of the Kelvin waves behind a ship moving at constant forward speed, corrected for viscous effects. The code uses thin ship and slender ship theories to obtain the hull singularity distribution, and axisymmetric boundary layer approaches to approximate the boundary layer flow over the hull surface. The spectral forms for obtaining the amplitude, spatial slopes, and resistance of the Kelvin waves are presented.</p> <p>A description is given of the general structure of the code. The input menus, by means of which data are interactively entered into the code, are explained in detail. Graphical representations are given for the spectra of a 300-ft long Series 60, $C_B = 0.60$ ship obtained by using various calculation options of the code.</p>				
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CONTENTS

1. INTRODUCTION	1
2. OUTLINE OF THEORETICAL METHOD	2
3. CALCULATION OF WAVE SPECTRA	3
4. STRUCTURE OF PROGRAM KELVIN	5
5. EXPLANATION OF MENUS AND INQUIRIES	8
6. NUMERICAL RESULTS	22
7. SUMMARY	23
8. REFERENCES	23



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KELVIN: AN INTERACTIVE COMPUTER CODE FOR THE KELVIN SPECTRUM WITH VISCOUS CORRECTIONS

1. INTRODUCTION

The calculation of the wave pattern created by a ship moving at constant speed on the ocean surface (commonly called the Kelvin waves) and the associated resistance due to these waves is an important area of study in naval architecture. The elevation and slopes of the waves may be of interest in ocean surface imaging applications. Wave resistance is one of the major components of total ship resistance.

The principal difference between the problem of a ship moving on the free surface and that of a body moving in infinite fluid is that in the first problem there is the need to satisfy the condition of constant pressure on the free surface, which is perturbed by the motion of the ship and hence not known a priori. This additional condition greatly complicates the solution of the problem. As a result, a wide variety of methods have been proposed. Many of these methods are discussed in two recent workshops on wave resistance in 1979 [1] and 1983 [2]. A brief survey of representative methods is also given by Wang [3]. The various methods essentially use potential flow approaches to satisfy the kinematic boundary condition of no flow through the ship hull and the dynamic pressure condition on the unknown free surface to varying degrees of accuracy. Some also attempt to account for the effect of viscosity. The complexity of the methods has ranged widely, from those which may be programmed on a minicomputer to those which require many hours on the most advanced supercomputers.

This report presents a description of the computer implementation and numerical results for a relatively simple method. Since it is described in detail by Wang [3,4], only a brief outline of the major features of the method is presented here. The method essentially uses the direct thin and slender ship theories to solve for the potential flow around the ship and uses axisymmetric integral momentum boundary layer methods to obtain the viscous corrections. A somewhat longer description is given of the uses which may be made of the complex wave amplitude spectrum, the principal output of the program. These include the generation of the well known wave resistance, the generation of the wave elevation and the wave slopes, and the extension of the spectrum from the monohull to a twin hull case. The computational model has been implemented in a computer program called KELVIN. A detailed description is given of the general structure of the program, its input options and output values.

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Graphical representations are given for the various spectra, with and without viscous corrections, for a 300-ft long Series 60, $C_B = 0.60$ ship. This is a ship model which has been extensively used in previous wave resistance studies. The report concludes with a summary of the major points.

2. OUTLINE OF THEORETICAL METHOD

The method consists of two major parts: the potential flow calculations and the corrections due to viscosity. The potential flow part consists of finding a potential ϕ which simultaneously satisfies Laplace's equation, the dynamic condition of constant pressure on the perturbed free surface, the radiation condition of no ship waves far upstream, and the kinematic condition of no flow through the ship hull. In the commonly used Green's function approach, the ship hull surface is divided into a series of panels, on each of which is placed a source of unknown strength, which satisfies Laplace's equation, the radiation condition, and approximately the troublesome free surface condition. The kinematic condition on the hull surface is then used to obtain the strengths of the singularities. This involves the calculation of the complex near-field terms of the Green's function to find the mutual influence of the sources. For many cases where the beam-to-length ratio of the ship is of moderate value, it is of sufficient accuracy to neglect the mutual influence of the sources, and directly obtain the source strength σ from the ship geometry

$$\sigma = \frac{-U}{4\pi} n_x \quad (1)$$

where U is the ship speed and n_x is the longitudinal component of the normal to the hull. This leads to zeroth order slender ship theory. If the beam-to-length ratio is still smaller, it is permissible to use thin ship theory, whereby the sources are placed on the vertical centerplane, and n_x is approximated by the longitudinal derivative of ship width

$$\sigma = \frac{-2U}{4\pi} \frac{\partial f}{\partial x} \quad (2)$$

where f is the local half-width of the ship.

Generally, potential flow solutions tend to predict wave resistances and elevations which are higher than those obtained from measurement. One reason is that the effect of viscosity tends to damp the wave elevations. A relatively simple, yet reasonably accurate, method for accounting for viscosity is to add the boundary layer displacement thickness to the hull. The net effect is to decrease the magnitude of σ in the stern region, where the boundary layer thicknesses are significant. In the present method, the hull is approximated by axisymmetric bodies which are equivalent in volume or wetted area to a double model of the actual hull. An axisymmetric momentum integral method is used to calculate the boundary layer flow over these bodies. It is shown by Wang [3,4] that for typical hull

shapes. this approximate correction using the equivalent volume model usually brings the calculated wave resistances into reasonable agreement with experimental values. For cases where the hull is of the form of a strut, i.e., with a large draft-to-beam ratio, a two-dimensional boundary layer approach may be preferable [4].

3. CALCULATION OF WAVE SPECTRA

The principal output of the computer program is the complex wave amplitude spectrum. Using the values of σ given in Eqs. (1) and (2), the wave amplitude spectrum A is obtained by using the formulation outlined by Eggers, Sharma, and Ward [5], resulting in

$$A(u) = \frac{k_0}{U} [G(u) + i F(u)] = \frac{2 [1 + \sqrt{1 + 4u^2}]}{\sqrt{1 + 4u^2}} J(u, s(u)) \quad (3)$$

$$\text{where } u = \frac{k_y}{k_0} = \frac{k}{k_0} \sin \theta = \sec \theta \tan \theta \quad (4a)$$

$$s(u) = \frac{k_x}{k_0} = \frac{k}{k_0} \cos \theta = \sec \theta = \sqrt{\frac{1}{2} (1 + \sqrt{1 + 4u^2})} \quad (4b)$$

$$w(u) = \frac{k}{k_0} = \sec^2 \theta = \sqrt{u^2 + s^2} \quad (4c)$$

$$k_0 = \frac{g}{U^2} \quad (4d)$$

$$J(u, s(u)) = 4\pi \int_S \sigma(x, y, z) \exp [k_0 (isx + iuy + wz)] dS. \quad (5)$$

The angle θ is measured between the longitudinal x -axis and the direction of propagation of a component wave, U is the ship speed, g is the gravity constant = 32.2 ft/sec², and S is the surface of integration. It is equal to the actual hull surface plus a contour integral at the free surface in the case of slender ship theory, and is equal to the ship vertical centerplane in the case of thin ship theory. The above formulation is given for a coordinate system, Figure 1, which is fixed to the ship with origin at the forward perpendicular, x positive from stern to bow, y positive to port, and z positive upwards. The quantities u and s are respectively the dimensionless wave numbers in the lateral y and longitudinal x directions, w is the resultant dimensionless wave number, and k_0 is the dimensional fundamental wave number. The complex function $J(u, s(u))$ is called the Kochin function and represents an integral over the hull surface of the source strength multiplied by an exponential wave function. The use of Eq. (4b) converts $J(u, s(u))$ from a function of two wavenumbers to a function of only one variable, $J(u)$.

It is of interest to note that the total Kochin function $J_T(u)$ for a twin hull ship with a vertical plane of symmetry is conveniently obtained from the Kochin function J for one hull. If the y -value of every point on the surface of the second hull, y' , is $2Y$ greater than the corresponding point on the first hull, i.e.,

$$y' = y + 2Y \quad (6)$$

then it is easy to see from Eq. (5) that the corresponding Kochin function for the second hull, J' , is related to J by

$$\begin{aligned} J'(u) &= 4\pi \int_S \sigma(x, y, z) \exp [k_0 (isx + iuy + iu2Y + wz)] dS \\ &= \exp (2iuY) J(u). \end{aligned} \quad (7)$$

From Eq. (3), the total wave amplitude function $G_T + iF_T$ for the twin hull ship is then simply given by

$$\begin{aligned} G_T(u) + iF_T(u) &= \frac{2[1 + \sqrt{1 + 4u^2}]}{\sqrt{1 + 4u^2}} [J + J' = J(1 + \exp (2iuY))] \\ &= (G + iF) [1 + \exp (2iuY)] \end{aligned} \quad (8)$$

The most direct use of the amplitude spectra is to use the inverse Fourier transform to obtain the wave elevation $\eta(x, y)$, the longitudinal slope $\eta_x(x, y)$, and the lateral slope $\eta_y(x, y)$, as follows

$$\eta(x, y) = \text{Re} \frac{1}{4\pi} \int_{-\infty}^{\infty} A(u) \exp [-ik_0 (sx + uy)] du \quad (9)$$

$$\eta_x(x, y) = \text{Re} \frac{1}{4\pi} \int_{-\infty}^{\infty} A_x(u) \exp [-ik_0 (sx + uy)] du \quad (10)$$

$$\eta_y(x, y) = \text{Re} \frac{1}{4\pi} \int_{-\infty}^{\infty} A_y(u) \exp [-ik_0 (sx + uy)] du \quad (11)$$

where $A(u) = \frac{k_0}{U} [G(u) + iF(u)]$, $A_x(u) = -ik_0 s(u) A(u)$, $A_y(u) = -ik_0 u A(u)$, and Re denotes the real part of the complex integral.

While the above are the most direct applications of the wave spectra, the most commonly used application is to obtain the wave resistance. In this case, the wave amplitude $A(u)$ is most conveniently given in terms of the wave direction θ and is also weighted by the term $\cos^3 \theta$ to express the

fact that the major contribution to the wave resistance is due to those waves whose directions of propagation are nearly aligned with the x-axis, as shown by Newman [6]. Using the relations between u and θ given in Eqs. (4) and the relation between $A(u)$ and $A(\theta)$ given in [5], which expresses the fact that $\eta(x,y)$ is the same, regardless of the independent variable, the following expression is obtained for the wave resistance spectrum $A^2(\theta) \cos^3 \theta$ in terms of $A^2(u)$ and u

$$\begin{aligned}
 A^2(\theta) \cos^3 \theta &= A^2(u) \left(\frac{du}{d\theta} \right)^2 \cos^3 \theta \\
 &= A^2(u) \cos^3 \theta \left[\frac{d}{d\theta} (\sec \theta \tan \theta) = \frac{1 + \sin^2 \theta}{\cos^3 \theta} \right]^2 \\
 &= A^2(u) \left[\frac{(2 - \cos^2 \theta)^2}{\cos^3 \theta} \right] \\
 &= A^2(u) \left[2s^3(u) - 2s(u) + \frac{1}{s(u)} \right] \tag{12}
 \end{aligned}$$

Similar transformations may be made to obtain the squared spectra $A^2(\theta)$, $A_x^2(\theta)$, and $A_y^2(\theta)$ in terms of u .

4. STRUCTURE OF PROGRAM KELVIN

This program calculates the Kelvin wave spectral function using either triangular or quadrilateral panels. Then, it computes the wave and viscous resistance with the effects of the boundary layer correction parameters for thin ship or slender ship approximation.

The KELVIN program is broken into five major parts: the main program and four modules. Refer to the diagram (1.0) below. The main program directs the logical flow of the program to perform the specified function within each module. Module SHIP_GEOMETRY directs the program to read and generate the input data. Module KELVIN_WAVE modifies the ship geometry for either thin or slender ship approximation with the effects of boundary layer correction factors. Then, module WAVE_SPECTRA calculates the wave and viscous resistance. Finally, module RESULTS controls the output options.

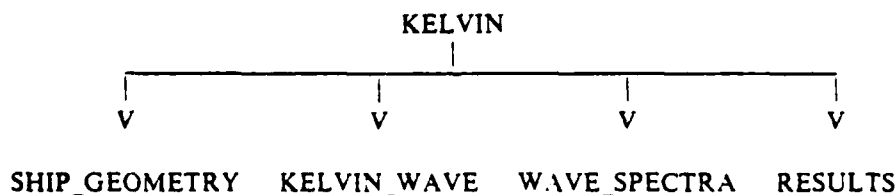


Diagram 1.0

Diagram (1.a) illustrates the general data flow of the KELVIN program. Reading either the HULLGEN file or the program generated data file for the ship geometry parameters, the BOUNDARY_LAYER routine defines the boundary layer correction parameters. The calculation phase begins by specifying the ship type approximation and the calculating option of the KELVIN_WAVE routine. Then, WAVE_SPECTRA calculates the wave and viscous resistance. After the KELVIN_WAVE and WAVE_SPECTRA routines have been completed once, the user has the option to go back and change the ship velocity, calling routine NEW_VELOCITY for the same thin or slender ship approximation. Between each case run, the RESULTS routine directs the output to either a line printer or a spectral output file.

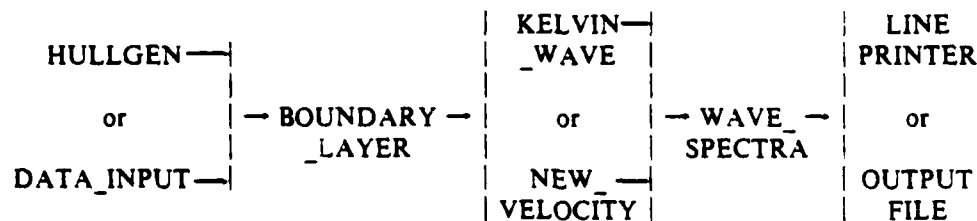
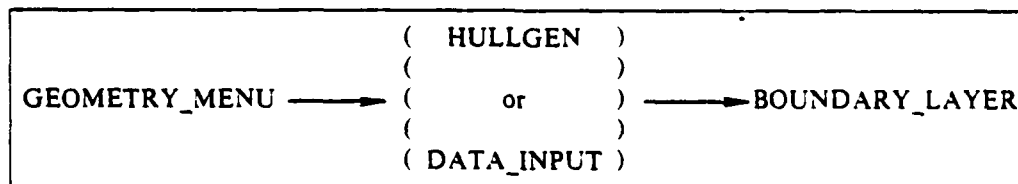


Diagram 1.a

4.1 Data Input

The SHIP_GEOMETRY module calls a menu, GEOMETRY_MENU, to select the source for the inputs. The user has the option to read from a HULLGEN file or to read the program generated dimensionless hull coordinates. If the user had chosen to read from the HULLGEN file, then the program is directed to the HULLGEN routine which will request for the name of the HULLGEN file. If the user had chosen to let the program generate the input data, then the program is directed to the DATA_INPUT routine which will request for the name of a ship geometry input file. A message on the screen will indicate to the user what type of ship hull he/she is working with. In both cases, if the program has problems opening the given file an error message will be displayed on the screen and it will repeat the request for correction.

SHIP_GEOMETRY Module



The next task in the SHIP_GEOMETRY module is to define the boundary layer correction parameters in the BOUNDARY_LAYER routine. The program will display the current parameter values on the screen and the user is given the opportunity to change any one of the parameter values using the interactive mode. Once the user is satisfied with the parameter values, he/she continues to the calculations phase.

4.2 Calculations

The calculations phase defines the case for calculating the wave resistance along the hull of the ship. The SHIP_MENU appears on the screen for the user to specify the type of approximation to be used. Then, the CALCULATIONS_MENU appears on the screen so the user can select the desired calculation process. The first time through the case, the user would select routine KELVIN_WAVE to do the complete modifications. Then, during the next runs he/she may select the NEW_VELOCITY routine to rerun the same case assigning a new value for the ship velocity.

Modules KELVIN_WAVE and WAVE_SPECTRA

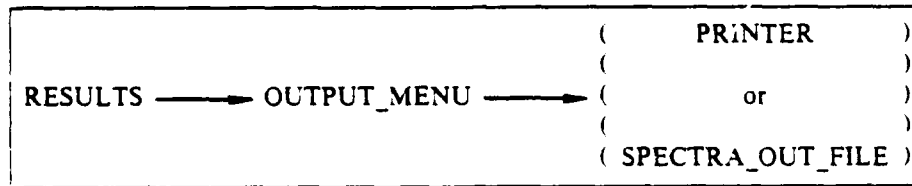
	(KELVIN_WAVE)	
	()	
SHIP_MENU — CALCULATIONS_MENU —	(or) —	WAVE_SPECTRA
	()	
	(NEW_VELOCITY)	

Once the KELVIN_WAVE or the NEW_VELOCITY routines have been completed, the program calls the WAVE_SPECTRA module to calculate the Kelvin wave spectral function due to line panel sources. Next, it calculates the wave and viscous resistance for the thin ship or slender ship approximation. Then, the program menu will appear on the screen so the user can direct his/her output to the module RESULTS.

4.3 Data Output

This phase routes the output results to the line printer or to a file to be used for KELSEA input. The OUTPUT_MENU lists the output options for the user to select from. At this point, the line printer and the spectral file are the only options.

RESULTS Module



Once the case is completed, the user has the option to run another case changing the approximation. NOTE : the user will have to re-enter the input data to get back the default values. The user guide example shows how the KELVIN program works.

5. EXPLANATION OF MENUS AND INQUIRIES

KELVIN is programmed to determine the viscous effects on ship wave resistance, applying the boundary layer correction factor. The main module directs the flow of the program to perform the major functional tasks to compute the viscous and wave resistance for either thin ship or slender ship approximation. Every time the program is loaded, the main program menu will appear on the screen as shown below.

```
.....
*
*      - FUNCTION MENU -
*
* (1) DATA INPUT - Generates Ship Geo-
*      metry and Boundary Layer Correction
*      parameters.
*
* (2) CALCULATIONS - Defines the case
*      for calculating the wave resistance
*      along the hull of the ship.
*
* (3) DATA OUTPUT - Routes output to
*      the line printer or file for KELSEA
*      input.
*
* (4) QUIT - Exit the program
*
*
*.....
```

ENTER the number code of desired function:

5.1 Data Input

For each and every new case analysis, the first function above, "DATA_INPUT", must be processed to define the ship geometry as well as the boundary layer correction parameters. Enter the appropriate function number.

ENTER the number code of desired function: 1

The INPUT OPTIONS menu is displayed on the screen so the user can make his/her input source selection. Follow the user's guide example and enter the code number below.

```
.....
*
*      - INPUT OPTIONS MENU -
*
*      (1) READ hull coordinates from
*          the HULLGEN file.
*
*      (2) READ program-generated
*          dimensionless hull coordinates.
*
*
*.....
```

ENTER the number code of desired option: 2

Having selected option #2, the DATA_INPUT routine will request the name of a ship geometry data file. Enter the filename, "KELVIN.DAT" to the inquiry below. If the user had entered a slash, the program would have continued to the next routine to define the boundary layer values.

```
.....
**** Specify the name of the data file from which      ****
**** this program will read the input data for the    ****
**** ship geometry (Enter / to exit).                  ****
**** File name: kelvin.dat                             ****
```

The following message on the screen is to inform the user which ship hull type was read from the data file. Enter a slash to continue to the BOUNDARY_LAYER routine.

```
*****
****   THE CURRENT SHIP HULL TYPE IS:   ****
****                                     ****
****   SHIP_TYPE = #1 ~ WIGLEY.         ****
****                                     ****
*****
```

PLEASE Type < / > to Continue: /

The next display will list the current boundary layer correction parameters. The user has the option to change any one of the values. Just answer yes as "Y" or "y", to the inquiry and then enter the item number of the boundary layer parameter value to be modified.

```
*****
****   PARAMETERS FOR BOUNDARY LAYER CALCULATIONS   ****
****   THE PRESENT PARAMETER VALUES ARE:           ****
****                                                 ****
****   (1) SHIP VELOCITY IN FT/SEC = 8.85           ****
****                                                 ****
****   (2) TYPE BODY FOR BL CALCULATIONS = 0        ****
****       .LE.0 ~~ VOLUME BODY                     ****
****       .GE.1 ~~ WETTED AREA BODY                ****
****                                                 ****
****   (3) SKIN FRICTION FORMULA = 0                 ****
****       .LE.0 ~~ COMPLEX GRANVILLE FORMULA      ****
****       .GE.1 ~~ SIMPLER LUDWIG-TILLMANN          ****
****                                                 ****
****   (4) BOUNDARY LAYER THICKNESS = 1              ****
****                                                 ****
****   (5) NUMBER OF ITERATIONS OF BOUNDARY LAYER    ****
****       CALCULATION = 4                           ****
****                                                 ****
****   Would you like to change any of the above boundary layer ****
****   parameters? (Y/N): y                          ****
****                                                 ****
****   ENTER THE ITEM NUMBER: 1                      ****
*****
```

Since the user has elected to change the value for the first item, the ship velocity, the following inquiry is given. Enter the new value or a slash for the default value which would be the current value shown. For the first time through the program, enter a slash for the default value.

```

*****
**** CURRENT VALUE OF SHIP VEL. IS: 8.85 FT/SEC ****
****                                     ****
**** PLEASE ENTER NEW VALUE FOR SHIP VELOCITY IN ****
**** FT/SEC -OR- ENTER (/) FOR DEFAULT VALUE: /

```

Below are the inquiries corresponding to the other boundary layer parameters. As was done above, the values were defaulted by entering a slash to each inquiry.

```

**** ENTER THE ITEM NUMBER: 2

```

```

*****
**** SPECIFY WHETHER YOU WANT TO USE VOLUME BODY ****
**** OR WETTED AREA BODY FOR BOUNDARY LAYER CALCS. ****
**** WHEN: ****
**** IREL.LE.0 ~ USE EQUIVALENT VOLUME BODY ****
**** FOR BOUNDARY LAYER CALCS. ****
**** ****
**** IREL.GE.1 ~ USE EQUIVALENT WETTED AREA ****
**** BODY FOR BOUNDARY LAYER. ****
**** ****
**** CURRENT VALUE IS: 0 ****
**** PLEASE ENTER NEW VALUE FOR IREL -OR- ****
**** ENTER (/) FOR DEFAULT VALUE: / ****

```

```

**** ENTER THE ITEM NUMBER: 3

```

```

*****
**** SPECIFY WHICH SKIN FRICTION FORMULA YOU WANT ****
**** TO USE: ****
**** ****
**** ICF.LE.0 ~ USE MORE COMPLEX GRANVILLE ****
**** SKIN FRICTION FORMULA. ****
**** ****
**** ICF.GE.1 ~ USE SIMPLER LUDWIG-TILLMANN ****
**** SKIN FRICTION FORMULA. ****
**** ****
**** CURRENT VALUE IS SET TO: 0 ****
**** PLEASE ENTER NEW VALUE FOR ICF -OR- ****
**** ENTER (/) FOR DEFAULT VALUE: / ****

```



```

**** ENTER THE ITEM NUMBER: 4
*****
**** SPECIFY WHETHER OR NOT YOU NEED TO ADD      ****
**** BOUNDARY LAYER THICKNESS TO SHIP HULL:      ****
****                                              ****
****      IBL.LE.0 ~ DO NOT ADD BOUNDARY LAYER    ****
****                  THICKNESS TO SHIP HULL.      ****
****                                              ****
****      IBL.GE.1 ~ DO ADD BOUNDARY LAYER THICK-  ****
****                  NESS TO THE SHIP HULL.        ****
****                                              ****
**** CURRENT VALUE IS SET TO: 1                   ****
**** PLEASE ENTER NEW VALUE FOR IBL -OR-          ****
**** ENTER (/) FOR DEFAULT VALUE: /              ****

**** ENTER THE ITEM NUMBER: 5
*****
**** SPECIFY THE NUMBER OF ITERATIONS FOR THE      ****
**** BOUNDARY LAYER CALCULATION.                  ****
****                                              ****
**** CURRENT VALUE FOR BOUNDARY LAYER ITERATIONS,  ****
**** (IBLIT), IS: 4                               ****
**** PLEASE ENTER NEW VALUE FOR IBLIT -OR-        ****
**** ENTER (/) FOR DEFAULT VALUE: /              ****

```

Between each inquiry, the boundary layer parameters are displayed as below to show the current or new values. However, in this case, the defaults were selected and the values remain as before. Once the user is satisfied with the values, he/she is to answer no to the inquiry asking if there are any changes to be made to the boundary layer correction parameters. Enter no as "N" or "n", and the program will return to the main menu.

```

*****
**** PARAMETERS FOR BOUNDARY LAYER CALCULATIONS  ****
**** THE PRESENT PARAMETER VALUES ARE:          ****
****                                              ****
**** (1) SHIP VELOCITY IN FT/SEC = 8.85          ****
****                                              ****
**** (2) TYPE BODY FOR BL CALCULATIONS = 0       ****
****      .LE.0 ~ VOLUME BODY                    ****
****      .GE.1 ~ WETTED AREA BODY                ****
****                                              ****
**** (3) SKIN FRICTION FORMULA = 0               ****
****      .LE.0 ~ COMPLEX GRANVILLE FORMULA      ****
****      .GE.1 ~ SIMPLER LUDWIEG-TILLMANN        ****
****                                              ****
**** (4) BOUNDARY LAYER THICKNESS = 1             ****
****                                              ****
**** (5) NUMBER OF ITERATIONS OF BOUNDARY LAYER  ****
****      CALCULATION = 4                         ****
****                                              ****
**** Would you like to change any of the above boundary layer ****
**** parameters? (Y/N): n                        ****

```

5.2 Calculations and Results

For each individual case, the KELVIN_WAVE routine must be processed first to complete the modifications for the ship hull surface with the effects of the boundary layer parameters. Then, the user can re-run the same approximation case changing only the ship velocity using the NEW_VELOCITY routine. Therefore, either KELVIN_WAVE or NEW_VELOCITY is processed before the WAVE_SPECTRA routine calculates the wave and viscous resistance.

To begin the calculations process enter the appropriate function number to the inquiry following the main menu below.

```
.....
*
*   - FUNCTION MENU -
*
* (1) DATA INPUT - Generates Ship Geo-
*      metry and Boundary Layer Correction
*      parameters.
*
* (2) CALCULATIONS - Defines the case
*      for calculating the wave resistance
*      along the hull of the ship.
*
* (3) DATA OUTPUT - Routes output to
*      the line printer or file for KELSEA
*      input.
*
* (4) QUIT - Exit the program
*
*.....
```

ENTER the number code of desired function: 2

The first request of the calculation function is to specify the ship approximation type. Enter the option for the thin ship given below.

```
.....
*
*   - SHIP MENU -
*
* Specify the type of approximation to be used
* in this case study:
*
* (1) Thin ship approximation.
*
* (2) Slender ship approximation.
*
*.....
```

ENTER the number code of desired option: 1

Then, the next menu below requests the calculation method. Since this is the first run through the thin ship approximation case, enter option 1 to process the complete modifications in the KELVIN_WAVE routine and to continue to the WAVE_SPECTRA routine.

```
.....
*
*      WAVE RESISTANCE      *
* - CALCULATION OPTIONS MENU - *
*
* (1) Calculate the ship geometry and wave *
*      resistance with boundary layer *
*      effects. *
*
* (2) Repeat calculation for a new value of *
*      the ship velocity. *
*
* (3) Exit to the function menu. *
*
*.....
```

ENTER the number code of desired option: 1

The screen will clear and display the message stating the type of ship approximation and another message stating that the calculating process is taking place.

```
**** - THIN SHIP APPROXIMATION - ****
**** Calculating wave resistance...
```

Once the first run has been successfully completed, the main menu will appear on the screen. Normally, the user will want to proceed to the RESULTS module to save the results. Enter "3" in response to the main menu inquiry.

```
.....
*
*      - FUNCTION MENU -      *
*
* (1) DATA INPUT - Generates Ship Geo- *
*      metry and Boundary Layer Correction *
*      parameters. *
*
* (2) CALCULATIONS - Defines the case *
*      for calculating the wave resistance *
*      along the hull of the ship. *
*
* (3) DATA OUTPUT - Routes output to *
*      the line printer or file for KELSEA *
*      input. *
*
* (4) QUIT - Exit the program *
*
*.....
```

ENTER the number code of desired function: 3

The OUTPUT OPTION menu will appear on the screen so the user may select his/her choice.
Follow the user's guide and enter the option number as below.

```

*****
*                                     *
*   - OUTPUT OPTION MENU -           *
*                                     *
*   (1) Output to line printer.       *
*                                     *
*   (2) Output file for KELSEA.       *
*                                     *
*****

```

ENTER the number code of desired choice: 1

Shown below are the results of a thin ship approximation using the program generated ship hull coordinates and defaulted boundary layer correction parameters.

```

>>>> THIN SHIP APPROXIMATION <<<<
>>>> VELOCITY = 8.85          <<<<

```

WIGLEY HULL,NSTA=25,NGRTHW=15, TEST FILE

NXSTATION = 25, NZSTATION = 15

**** XXS ****

-1.0000	-.9500	-.9000	-.8500	-.8000	-.7000	-.6000	-.5000
-.4000	-.3000	-.2000	-.1000	0.0000	.1000	.2000	.3000
.4000	.5000	.6000	.7000	.8000	.8500	.9000	.9500
1.0000							

**** ZZS ****

-1.0000	-.9290	-.8570	-.7860	-.7140	-.6430	-.5710	-.5000
-.4290	-.3570	-.2860	-.2140	-.1430	-.0710	0.0000	

Length at Waterline	=	20.0000
Wetted Surface Area	=	59.5567
Twice Projected Area	=	50.0000
Displacement (L Tons)	=	.6580

Total Number of Panels	=	336
Norm. Source Strength	=	.141086E+00

BEAM B = 2.0000, DRAFT H = 1.1895

I	XSTATION	RS	RV
1	-20.0000	.7958	.6117
2	-19.5000	.7991	.5375
3	-19.0000	.8081	.5304
4	-18.5000	.8217	.5963
5	-18.0000	.8387	.6563
6	-17.0000	.8784	.7610
7	-16.0000	.9204	.8422
8	-15.0000	.9605	.9059
9	-14.0000	.9959	.9551
10	-13.0000	1.0247	.9918
11	-12.0000	1.0459	1.0170
12	-11.0000	1.0589	1.0317
13	-10.0000	1.0631	1.0363
14	-9.0000	1.0586	1.0309
15	-8.0000	1.0454	1.0150
16	-7.0000	1.0238	.9879
17	-6.0000	.9946	.9490
18	-5.0000	.9591	.8968
19	-4.0000	.9189	.8286
20	-3.0000	.8771	.7401
21	-2.0000	.8379	.6229
22	-1.5000	.8212	.5470
23	-1.0000	.8079	.4526
24	-.5000	.7990	.3246
25	0.0000	.7958	0.0000

WIGLEY HULL,NSTA=25,NGRTHW=15, TEST FILE

***** AT 5.2 KNOTS

WAVE RESISTANCE = 5.10727 (POUNDS)
CWV * 1000 = 10.9585
CWS * 1000 = 1.10163
FROUDE NUMBER = .348880

DENSITY = 1.99000 KINEMATIC VISCOSITY = .14600E-04

RVH = 0.00000 , RVS = 36.1197 , RT = 41.2270

DISP(LT) = .417850 , CB(FT) = -10.2968, NORM SS = .282172

The main program menu will appear on the screen. To re-run the same approximation changing only the ship velocity, follow the steps below. First, enter the code number for the calculations function given here.

```

.....
*
*           - FUNCTION MENU -
*
* (1) DATA INPUT - Generates Ship Geo-
*       metry and Boundary Layer Correction
*       parameters.
*
* (2) CALCULATIONS - Defines the case
*       for calculating the wave resistance
*       along the hull of the ship.
*
* (3) DATA OUTPUT - Routes output to
*       the line printer or file for KELSEA
*       input.
*
* (4) QUIT - Exit the program
*
.....

```

ENTER the number code of desired function: 2

Since the user does not wish to change the approximation, enter a slash to the following inquiry. An error message would occur if the user tries to use the NEW_VELOCITY routine before reading or re-reading the data input to set back the default values or before completing the KELVIN_WAVE routine first.

```

.....
**** The current type of ship approximation is:      ****
****                                                    ****
**** - THIN SHIP APPROXIMATION -                      ****
****                                                    ****
**** Enter </> for no change in specified            ****
**** approximation -OR-                               ****
**** Press any key for the SHIP MENU.  :/            ****

```

This time enter the code number for repeating the calculation process using a new value for the ship velocity.

```
.....
*
*      WAVE RESISTANCE
* - CALCULATION OPTIONS MENU -
*
* (1) Calculate the ship geometry and wave
*      resistance with boundary layer
*      effects.
*
* (2) Repeat calculation for a new value of
*      the ship velocity.
*
* (3) Exit to the function menu.
*
*
*.....
```

ENTER the number code of desired option: 2

The NEW_VELOCITY routine presents the current velocity value and requests the "new" ship velocity in feet per second. Enter the value of the new velocity below.

```
.....
**** Specify the New ship velocity in ft/sec.      ****
**** Current ship velocity is: 8.85 ft/sec.         ****
****
**** Please enter the New velocity for the ship in  ****
**** ft/sec.: 8.0
```

Once again the screen will clear and display the message stating the type of ship approximation and another message stating that the calculating process is taking place. Note, only WAVE_SPECTRA is being processed.

```
**** - THIN SHIP APPROXIMATION - ****
**** Calculating wave resistance...
```

The main menu will appear on the screen after successfully completing the calculations process.
Enter the code number for the RESULTS module.

```
.....
*
*      - FUNCTION MENU -
*
*  (1) DATA INPUT - Generates Ship Geo-
*      metry and Boundary Layer Correction
*      parameters.
*
*  (2) CALCULATIONS - Defines the case
*      for calculating the wave resistance
*      along the hull of the ship.
*
*  (3) DATA OUTPUT - Routes output to
*      the line printer or file for KELSEA
*      input.
*
*  (4) QUIT - Exit the program
*
*
*.....
```

ENTER the number code of desired function: 3

Again, the OUTPUT OPTION menu appears on the screen. Follow the user's guide and enter the option number below.

```
.....
*
*      - OUTPUT OPTION MENU -
*
*  (1) Output to line printer.
*
*  (2) Output file for KELSEA.
*
*
*.....
```

ENTER the number code of desired choice: 1

Shown below are the results of a thin ship approximation using the program generated hull coordinates and the defaulted boundary layer correction parameters, including the new ship velocity.

>>>> THIN SHIP APPROXIMATION <<<<
>>>> VELOCITY = 8.00 <<<<

WIGLEY HULL.NSTA=25.NGRTHW=15, TEST FILE

NXSTATION = 25, NZSTATION = 15

**** XXS ****

-1.0000	-.9500	-.9000	-.8500	-.8000	-.7000	-.6000	-.5000
-.4000	-.3000	-.2000	-.1000	0.0000	.1000	.2000	.3000
.4000	.5000	.6000	.7000	.8000	.8500	.9000	.9500
1.0000							

**** ZZS ****

-1.0000	-.9290	-.8570	-.7860	-.7140	-.6430	-.5710	-.5000
-.4290	-.3570	-.2860	-.2140	-.1430	-.0710	0.0000	

Length at Waterline	=	20.0000
Wetted Surface Area	=	59.5567
Twice Projected Area	=	50.0000
Displacement (L Tons)	=	.6580

Total Number of Panels	=	336
Norm. Source Strength	=	.141086E+00

BEAM B = 2.0000, DRAFT H = 1.1895

I	XSTATION	RS	RV
1	-20.0000	.7958	.6117
2	-19.5000	.7991	.5375
3	-19.0000	.8081	.5304
4	-18.5000	.8217	.5963
5	-18.0000	.8387	.6563
6	-17.0000	.8784	.7610
7	-16.0000	.9204	.8422
8	-15.0000	.9605	.9059
9	-14.0000	.9959	.9551
10	-13.0000	1.0247	.9918
11	-12.0000	1.0459	1.0170
12	-11.0000	1.0589	1.0317
13	-10.0000	1.0631	1.0363
14	-9.0000	1.0586	1.0309
15	-8.0000	1.0454	1.0150
16	-7.0000	1.0238	.9879
17	-6.0000	.9946	.9490
18	-5.0000	.9591	.8968
19	-4.0000	.9189	.8286
20	-3.0000	.8771	.7401
21	-2.0000	.8379	.6229
22	-1.5000	.8212	.5470

23	-1.0000	.8079	.4526
24	-.5000	.7990	.3246
25	0.0000	.7958	0.0000

WIGLEY HULL.NSTA=25.NGRTHW=15. TEST FILE

***** AT 4.7 KNOTS

WAVE RESISTANCE = 4.86916 (POUNDS)
 CWV * 1000 = 12.7857
 CWS * 1000 = 1.28531
 FROUDE NUMBER = .315372

DENSITY = 1.99000 KINEMATIC VISCOSITY = .14600E-04

RVH = 0.00000 , RVS = 29.9643 , RT = 34.8335

DISP(LT) = .417850 , CB(FT) = -10.2968, NORM SS = .282172

The main program menu will appear on the screen after the print job is completed. Enter the function code below to exit the program and to conclude the two cases.

```

*****
*
*           - FUNCTION MENU -
*
* (1) DATA INPUT - Generates Ship Geo-
*      metry and Boundary Layer Correction
*      parameters.
*
* (2) CALCULATIONS - Defines the case
*      for calculating the wave resistance
*      along the hull of the ship.
*
* (3) DATA OUTPUT - Routes output to
*      the line printer or file for KELSEA
*      input.
*
* (4) QUIT - Exit the program
*
*****

```

ENTER the number code of desired function: 4

6. NUMERICAL RESULTS

Program KELVIN has been run to obtain the squared spectra defined in Section 3. The runs were made for a 300-ft long model of the Series 60, $C_B = 0.60$ hull, which is one of the test cases for the wave resistance workshops described in [1] and [2]. The runs were made for the ship moving at a speed of 18.6 knots, corresponding to a Froude number Fn of 0.32, where Fn is given by

$$Fn = \frac{U}{\sqrt{gL}} \quad (13)$$

and L is the length of the ship. This hull has a beam-to-length ratio B/L equal to 0.133, and a draft-to-length ratio H/L equal to 0.053. Figure 2 shows a sketch of the section shapes at a series of longitudinal stations.

A total of four runs were made:

- (1) thin ship theory with no viscous correction
- (2) slender ship theory with no viscous correction
- (3) slender ship theory including the viscous correction
- (4) slender ship theory including the viscous correction for a twin hull ship with the centerplane situated 80 ft ($=2B$) from each hull.

Figures 3, 4, 5, and 6 respectively show the squared spectra $A^2(\theta)$, $A^2(\theta) \cos^3 \theta$, $A_x^2(\theta)$, and $A_y^2(\theta)$ for each of these four cases. The spectra for the twin hull case have been divided by 2 to make them comparable in magnitude with the monohull cases. The spectra are shown for values of θ up to 72 degrees. At higher values of θ , the spectra for some cases take on large values and also oscillate rapidly with θ . Also, the accuracy of the present potential flow approaches decreases with increasing θ , where the wavenumber k increases (see Eq. (4c)), i.e., wavelength decreases. To accurately model the short wavelength region it is necessary to account for the interaction between the sources on the hull, which is neglected in the present potential flow approaches.

The results basically show that for this hull, there is a relatively large difference between thin ship and slender ship theories. The effect of the viscous correction is to generally lower the spectral values, with little phase shift. On the other hand, the effect of the twin hull is to cause a shift in the location of the maximum and minimum values of the spectra, along with changes in their magnitudes. The spectral levels for the y -slope are significantly higher than those for the x -slope, by as much as a factor of 10. The spectra for A^2 , A_x^2 , and A_y^2 all show the trend of increasing with θ . On the other hand, the wave resistance spectrum $A^2 \cos^3 \theta$, which weights the lower values of θ , tends to have a more broad band appearance.

7. SUMMARY

The present method uses the direct thin and slender ship theories to calculate the potential flow and an axisymmetric integral momentum method to obtain the viscous corrections. It is shown that the resultant elevation spectrum for the Kelvin waves may be conveniently transformed to give spectra for the wave resistance, longitudinal and lateral slopes, and the influence of a second hull. A detailed description is given of program KELVIN, which represents the computer implementation of the theoretical model. For the case of the widely used Series 60, $C_B = 0.60$ hull, the results show that there is a relatively large difference between thin ship and slender ship cases, and smaller differences for the corrections due to viscosity, and the presence of a twin hull. The elevation and slope spectra tend to increase with wave direction θ while the traditional wave resistance has a more broad band appearance.

8. REFERENCES

1. Bai, K.J. and McCarthy, J.H. (ed.), *Proceedings of the Workshop on Ship Wave-Resistance Computations*, DTNSRDC, November 1979.
2. Noblesse, F. and McCarthy, J.H. (ed.), *Proceedings of the Second DTNSRDC Workshop on Ship Wave-Resistance Computations*, DTNSRDC, November 1983.
3. Wang, H.T., "Calculation of Viscous Effects on Ship Wave Resistance Using Axisymmetric Boundary Layer Approaches," Naval Research Laboratory Report 8881, May 1985.
4. Wang, H.T., "Calculations of Viscous Effects on Ship Wave Resistance Using Simplified Boundary Layer Approaches," *Proceedings of the Fourth International Conference on Numerical Ship Hydrodynamics*, September 1985.
5. Eggers, K.W.H., Sharma, S.D., and Ward, L.W., "An Assessment of Some Experimental Methods for Determining the Wavemaking Characteristics of a Ship Form," *Transactions of the Society of Naval Architects and Marine Engineers*, Vol. 75, pp. 112-157, November 1967.
6. Newman, J.N., *Marine Hydrodynamics*, The MIT Press, Cambridge, Massachusetts, 1977.

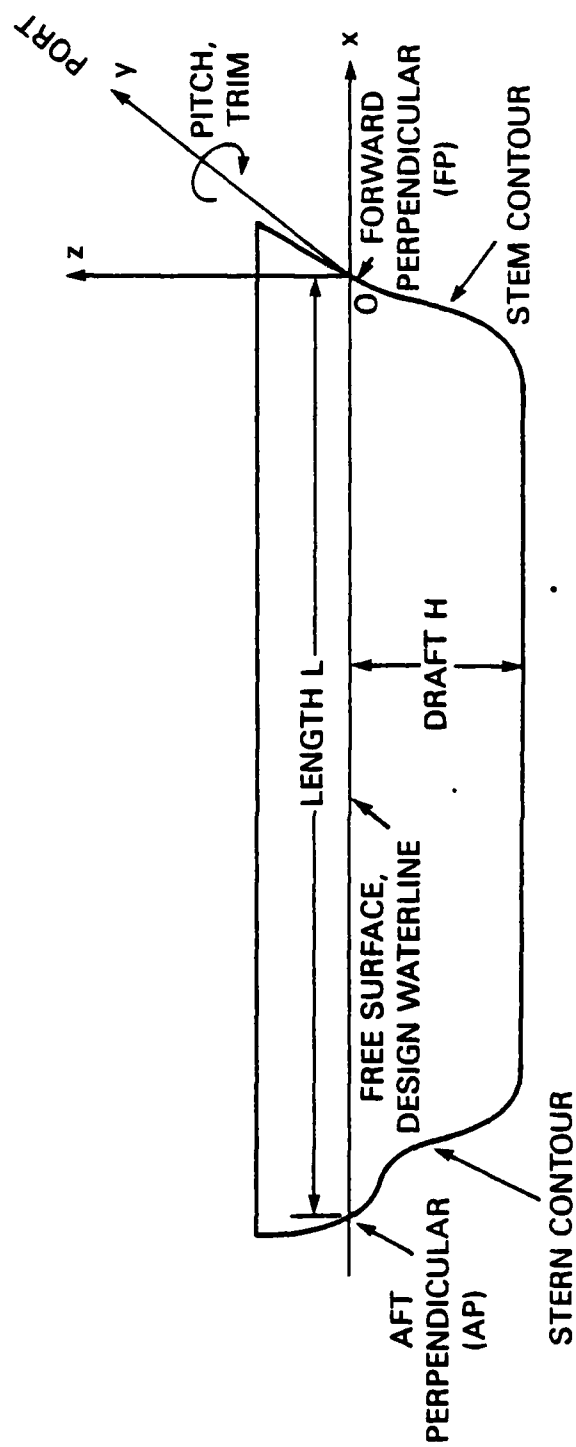


Fig. 1 — Ship configuration and coordinate system

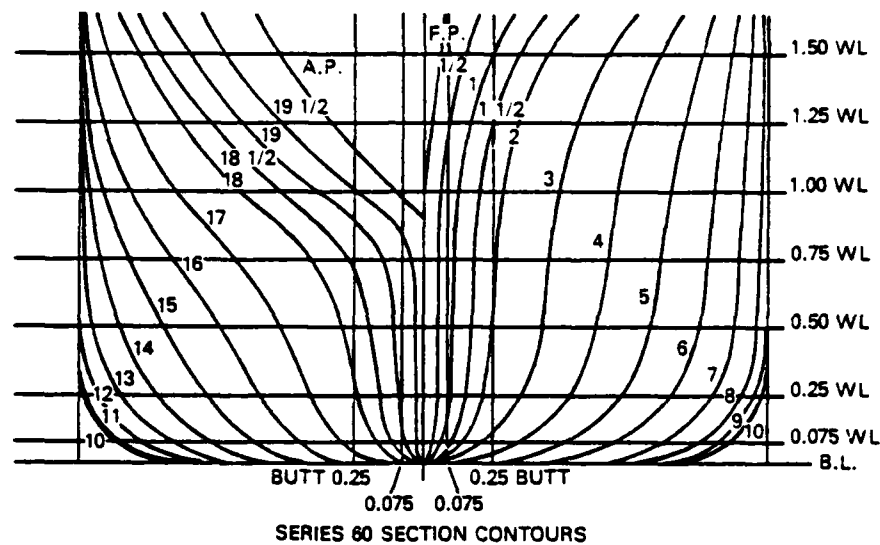


Fig. 2 — Geometric description of Series 60, $C_B = 0.60$ hull

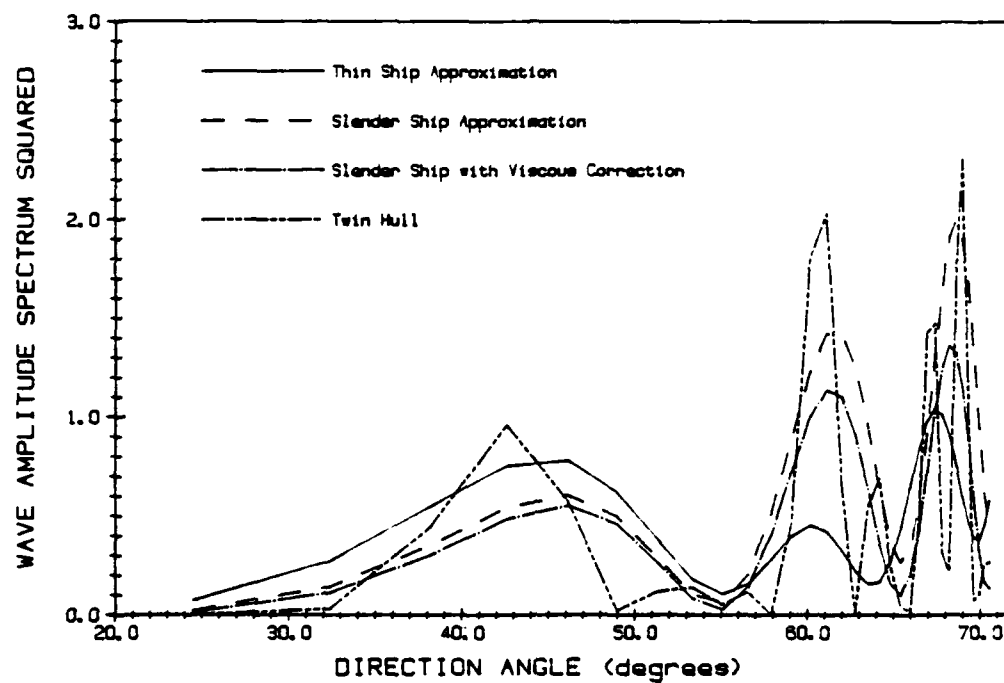


Fig. 3 — Square of wave amplitude spectrum

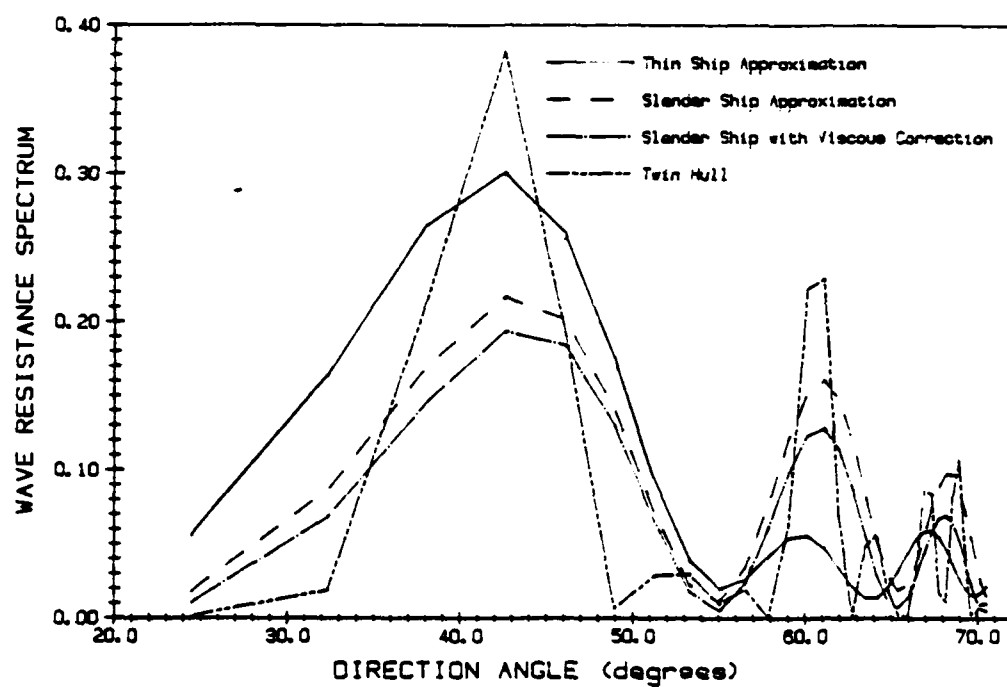


Fig. 4 — Wave resistance spectrum

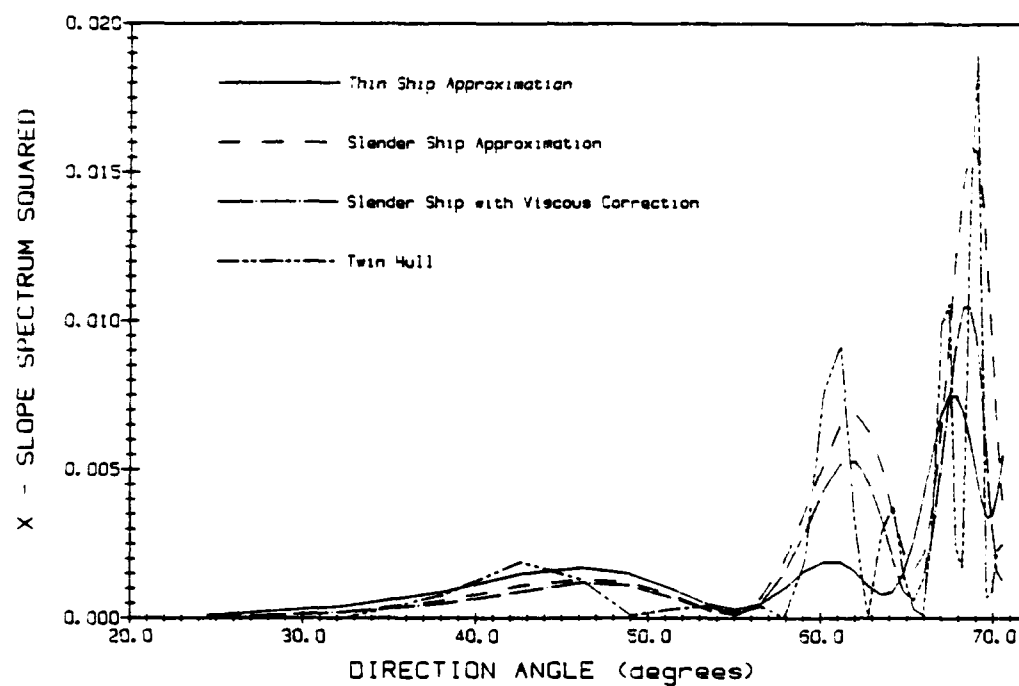


Fig. 5 — Square of x-slope spectrum

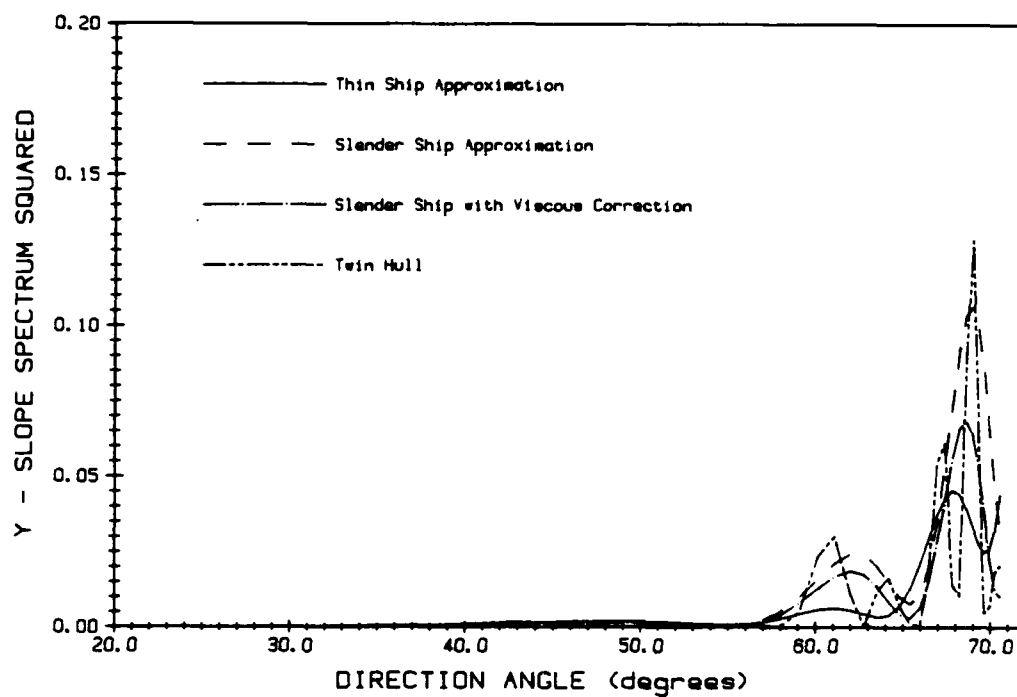


Fig. 6 — Square of y -slope spectrum

END

1/1-S6

DTIC